Water relations balance parameters of 30 woody species from Cerrado vegetation in the wet and dry season

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Abstract The water relations balance parameters of plant tissue have been determined under field condition. They are the osmotic potentials at saturation (πsat), the osmotic potentials at the turgid loss point (πtlp), modulus of elasticity (ε) and the water saturation deficiency at turgid loss point (*Wsdtlp*) of 30 adult woody species from Cerrado vegetation (neotropical savanna) in the wet and dry seasons of Brazil. And the changing patterns of *Se* values of each species have been compared and analyzed in different methods. The mean values of πsat, πtlp, ε and *Wsdtlp* of 30 species in the wet season were -2.11 MPa, -2.50 MPa, 19.66 MPa and 10.27 % respectively. Responding to water stress in the dry season, the values of πsat of 24 species, the πtlp and the ε of 17 species, the *Wsdtlp* of 6 species significantly went down or up comparing with those in the wet season ($P < 0.05$). Only 3 species had not changed their water parameters significantly any more. The mean values of πsat, πtlp, ε and *Wsdtlp* of 30 species were adjusted to be -2.28 MPa, -2.84 MPa, 18.58 MPa and 8.19 % respectively. The species that have lower values on the πsat have higher values on ε. Contrary, the species that have higher values on the πsat have lower values on ε. The special strategies of 30 Cerrado species have been divided into 3 types in Cluster Analysis Method. Every type has the distinct water balance mechanism and the parameter-adjusting pattern.

Key words: Neotropical savanna, Osmotic potential, Modulus of elasticity, Wet and dry season

Introduction

The higher plants maintaining their organs to be turgid are very important mechanism, in which the all-physiological process could function normally under the limited water stress (Meinzer *et al* 1986). The season adjustment in water relation of woody species often occurs responding to the changing environmental conditions in order to maintain a soil-to-leaf water potential gradient and lower the wilting point by extending the range of positive turgid (Kubiske & Abrams 1991). Although there were a lot of arguments on the water relation in past decades, plant water potential and the tissue osmotic, the cell wall elastic adjustment and the relative water content had been considered as to be fundamental (Kramer 1988). The importance and internal mechanism for plants to maintain their water balance adjusted by the water relation parameters have been discussed extensively. And nowadays the more attention has been paid to the multifactorial system, non-linear processes and change of water relation parameters in order to achieve the optimum response to water stress. In this sense, it is reasonable to evaluate comprehensively on the plant water balance mechanism by the means of multiple parameters and their changing patterns.

Cerrado vegetation, a kind of neotropical savanna, covers about 1,800,000 km^2 in Brazil and shows different physiognomic types, which is an important kind of vegetation in this country. The distinct wet and dry seasons occur every year repeatedly in this area. The ability for the plant to balance water relation plays a very important role in survivor and biomass production under the seasonally severe water stress. However, the research work on the water relation parameters of woody plant in Cerrado vegetation is rare (Prado *et al* 1994). Especially, the comprehensive analysis on a few of water relation parameters and their changing tendency to understand the strategy and mechanism of water balance has not been read.

This work has selected 30 important component species in Cerrado vegetation to study their water balance mechanisms adjusted by the osmotic and elastic property parameters in the wet and dry season. The principal aim is to determine the principal parameters of water relation, to analyze and compare the relations between the πsat and ε in different seasons, to analyze 4 water relation parameters comprehensively and to explore the main types of mechanism of woody plant maintaining water balance in the Cerrado area.

Materials and methods

The study was carried out at the Federal University of Sao Carlos in Brazil. The samples were selected

from the Cerrado reservoir locating in the north area of Sao Carlos city (22°00′ ~ 22° 30′ S and 47° 30′ ~ 48° 00′ W). Using the method of Koeppen climate classification, this region is the transition between Aw and Cwa, with the mean temperature of 18.1 °C during the coldest month and 23.1 °C in the hottest month. The mean precipitation is 24.10 mm in the driest month and 285.95 mm in the wettest month. All measurements were carried out in the wet season, January-February of 1996 and dry season, July-August of 1996.

30 adult woody species (Table 1) are selected, which play an important role in the component of Cerrado vegetation. And they all grow healthily and have achieved at adult age in the field condition. For every species, the leaves fully expending or twigs from middle or upper canopy, both without signs of premature, infection and senescence, were cut and cut again under water. Then they were sealed in a humid container and transported back to the laboratory in the evening. The leaves or twigs were dehydrated until sufficient turgidity in the beaker during 12~16 h in dark.

Small branches or leaves covered with plastic film, the pressure-volume curves (*p/v*, $1/\pi$ vs. *Wsd*) were derived with the Santa Barbara Soil Moisture Pressure Chamber, model 3,005, made in USA. As the chamber was pressurized with the compressed nitrogen, the expressed sap was collected by small piece of cotton wrapped by tissue paper which were weighted by electronic balance (0.1 mg precision; Metler AE 260, made in Japan) before and after each sap collection. The chamber pressure was successively raised from 0.1 MPa to 0.3 MPa increment and for each increment a new equilibrium of pressure should be achieved. The data were plotted as the reciprocal of balance pressure on the ordinate vs. water saturation deficiency (*Wsd*). The fresh weight of leaves or twigs was taken after pressurization and dry weight was obtained after oven drying in 48 h at 80 °C, which was necessary for the calculation of water saturation deficiency (*Wsd*).

From the *p/v* curves, the πsat, the πtlp, the ε, and the *Wsdtlp* were derived. For every sample, πsat was estimated via linear regression of data in the straight-line region of the *p*/v curves; the πtlp and the *Wsdtlp* were derived from the *x* and *y* ordinates respectively, at the first point in the straight-line region of *p*/v curves. The ε and *Wsd* were calculated by following equations:

$\varepsilon = \Delta p / (\Delta V / V)$;

Wsat = (*FWAP* + *TSE*) -*DW*;

Wact= *Wsat* - *Sap Extract*;

Wsd= [(*Wsat* - *Wact*)/*Wsat*] × 100%;

Where ε: modulus of elasticity;

Δp: change of turgid pressure (MPa);

ΔV: change of leaf tissue volume responding to Δp (mL);

V: total leaf tissue volume (mL);

Wsat: water weight of leaf in saturation condition (g);

FWAP: leaf fresh weight after pressure (g);

TSE: total sap extract;

DW: leaf dry weight; *Wact*: actual leaf water weight (g);

Wsd: water saturation deficit (%) (more detail refer to Culter *et al* 1986; Kubiske *et al* 1991; Larcher 1995).

The measurements for every species were repeated at least three times in order to lessen the error to a great extent. The mean value and corresponding standard error were calculated statistically. The 4 values of water parameters of 30 species at different seasons were compared respectively and subjected to one-way Analysis Variance ($P < 0.05$ or 0.01)

The hierarchical tree of the strategies of water balance among 30 species was been built up after the Cluster Analysis with joining (tree clustering) algorithm. The distance of different species in multidimensional space was computed by the Euclidean Distance {distances $(x, y) = \{\Sigma (x_i - y_i)^2\}^{1/2}$ When linked the different species, the Complete Linkage (Furthest Distance) method was used (Pielou 1984). The process of Cluster Analysis was carried out by software (Statistics for windows, Release 4.3®, Statsoft Inc. 1993).

Results and discussion

The changing pattern of four water balance parameters in different seasons

The values of the πsat, the πtlp, the ε and the *Wsdtlp* with the corresponding standard error (*Se*) of 30 woody species from Cerrado vegetation in the wet and dry season have been shown in Table 1. From this table, we could learn that the mean values of the πsat, the πtlp, ε and the *Wsdtlp* of 30 species are -2.11 MPa, -2.50 MPa, 19.66 MPa and 10.27 % respectively in the wet season. Although there are kinds of the congenial revolutions among different species which perform uniform appearance under the similar environment (Rundel 1991), the results of 30 species showed the diverse strategies to maintain water balance in its organs and to survive responding to water stress. In the wet season, the highest value of πsat is -1.23 MPa (*Solanum lycocarpum*) and the lowest value of πsat is -2.96 MPa (*Memora axillaris*). The range of πtlp is from -1.45 MPa (*Anacardium nanum*) to -3.35 MPa (*Memora axillaris*). The highest value of ε is 44.72 MPa (*Duguetia furfuraceae*) and the lowest value is 8.03 MPa (*Bahuinia holophylla*).

The range of the *Wsdtlp* is from 3.21 % (*Anacardium nanum*) to 15.99 % (*Didymopanax vinosum*).

In the dry season, the water parameters, the *πsat*, the *πtlp*, ε and the *Wsdtlp* of most species have changed responding to the water stress. The *πsat* of 24 species, the *πtlp and the* ε *of 17 species, the Wsdtlp of 7 spec*ies increased or decreased significantly ($P< 0.05$ or 0.01). Only 3 species have not changed their water parameters significantly any more. The mean value of water relation parameters of 30 species for the *πsat* is -2.28 MPa, decreasing 7.99 %, the *πtlp* is -2.84 MPa, decreasing 13.26 %, ε is 18.58 MPa, decreasing 5.45 %; and the *Wsdtlp* is 8.19%, decreasing 20.22% respectively. The highest value of *πsat* is -1.73 MPa (*Erythroxylon sp.*) and the lowest is -3.04 MPa (*Erythroxylon suberosum*). The highest value of ε is 39.55 MPa (*Stryhnodendron barbadetima*) and the lowest is 7.42 MPa (*Erythroxylon sp.* in Table 1). From this result, we believed that the most Cerrado species in the dry season adjusted their mechanism to strengthen ability to absorb water from drier soil by maintaining a soil-to-leaf water potential gradient (*πsat, πtlp,* go down) while other species lowered the water content for maintaining their organs to be turgid (the *Wsdtl* decreased, Kubiske *et al* 1991). On the other hand, some species have strengthened the ability to store water in their bodies (ε become lower) in response to the severe water stress in the dry season.

Kozlowski *et al* (1991) demonstrated that the osmotic adjustment range is less than 0.1 MPa for woody species. In Cerrado, for given species, the range of adjustment of 4 water balance parameters between the wet and dry season is as followed: the *πsat* is less than 0.92 MPa (*Erythroxylon suberosum*); the *πtlp* is less then 1.05 MPa (*Anacardium nanum*); the ε is less than 27.7 MPa (*Duguetia furfuracea*); the *Wsdtlp* is less than 9.85 % (*Stryphnodendron barbadetima*).

Larcher (1995) demonstrated the osmotic potential of deciduous wood species of temperate zone is -0.9 ~ -2.7 MPa, and that of sclerophylls is -1.2 ~ -5.0 MPa. Meanwhile, he pointed out the modulus of elasticity for the deciduous species were 10 ~ 20 MPa, the evergreen were 30 ~ 50 MPa. It is clear that the range of *πsat* (-1.23 ~ -3.04 MPa) and the range of ε (7.42 ~ 44.72 MPa) of Cerrado species only could be substantiated partly by the result of Larcher (1995). On the other hand, Prado & Moraes (1996) found that mean value of photosynthetic capacity on area or mass basing in 20 woody species of Cerrado vegetation under field condition is between deciduous and evergreen species. The situation of 4 water relation parameters is somewhat similar to that of the photosynthesis capacity.

The relation between the *πsat* and the ε of 30 species from Cerrado

The relation between the *πsat* and ε of 30 species from Cerrado could be shown as a curve-linear (parabola in Fig. 1) regardless the wet season or dry season. However, the parameters of equations were changed between different season. In the wet season the relation between the *πsat* and the ε could be expressed by the equation:

y=-0.4724-0.1121x +0.0013x^2

y: osmotic potential at saturation (*πsat*);

x: modulus of elasticity (ε).

The corresponding the equation on the relation between the *πsat* and the ε in the dry season is:

y = -0.9951-0.0944x + 0.0012 x^2.

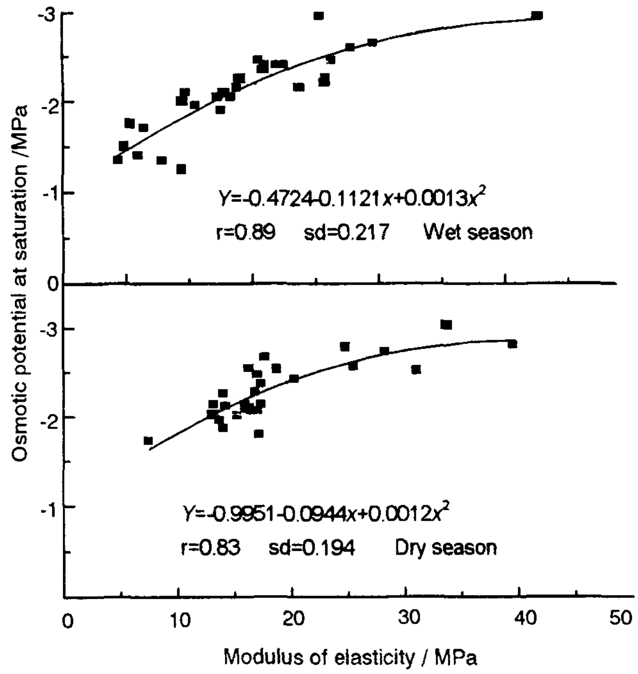

Fig. 1. The relation between the osmotic potential at saturation (*πsat*) and modulus of elasticity (ε) of 30 species from Cerrado in the wet season (above) and dry season (bottom)

It is clear that the values of the *πsat* and the ε of 30 species regardless the wet or dry season are higher value to lower value. In the similar condition of water stress, some species have the lower values of the *πsat* in order to maintain the water balance, which means their ability to get water from soil is stronger. And the higher values of the ε, which means the ability to store water in the organs is weaker (*Duguetia furfuracea, Memora axillaris*) (Larcher 1995). Contrary, some species have higher values of the *πsat* and the lower values of the ε (*Bahuinia holophylla, Tibouchina*), the strategies to balance the

Table 1. The comparison of water relation balance parameters from Cerrado between the wet (during January-February 1996) and dry season (during July-August 1996)

No.	Species	Wet season πsat / MPa	Se / MPa	πtlp / MPa	Se / MPa	ε / MPa	Se / MPa	Wsdtlp %	Se %
1	*Anacardium nanum*	-1.36	0.02	-1.45	0.04	12.76	0.07	3.30	2.34
2	*Anadenanthera falcata*	-2.25	0.04	-2.60	0.14	26.10	0.30	10.10	8.26
3	*Annona coriacea*	-2.16	0.03	-2.35	0.04	23.71	0.22	7.54	5.26
4	*Aspidosperma tomentosun*	-2.39	0.00	-2.88	0.09	20.94	0.09	11.76	9.12
5	*Bahuinia holophylla*	-1.52	0.01	-1.98	0.02	8.03	0.58	14.62	12.36
6	*Bowdichia virgilioides*	-2.09	0.03	-2.50	0.00	18.25	0.66	17.48	13.00
7	*Campomanesia aromatica*	-2.31	0.01	-2.70	0.07	23.92	0.45	6.26	5.15
8	*Campomanesia sp.*	-2.63	0.01	-3.00	0.00	27.96	0.25	10.03	7.26
9	*Caryocar brasiliense*	-1.71	0.00	-2.20	0.00	11.34	0.59	15.17	10.47
10	*Casearia sylvestris*	-2.46	0.03	-2.73	0.05	26.27	1.01	9.34	6.88
11	*Connarus suberosus*	-2.25	0.04	-2.63	0.05	18.01	0.12	8.30	6.23
12	*Didymopanax vinosum*	-1.95	0.09	-2.35	0.04	14.81	1.65	15.99	9.84
13	*Diospyros sp.*	-2.11	0.01	-2.45	0.04	14.65	0.66	8.63	5.99
14	*Duguetia furfuracea*	-2.89	0.00	-3.33	0.05	44.72	0.65	3.21	2.30
15	*Erioteca gracilipes*	-2.10	0.04	-2.75	0.11	17.73	0.59	10.60	6.64
16	*Erythroxylon sp.*	-2.35	0.04	-2.85	0.04	21.93	0.38	11.58	8.58
17	*Erythroxylon suberosum*	-2.12	0.01	-2.60	0.21	20.07	0.18	12.42	6.06
18	*Memora axillaris*	-2.96	0.07	-3.35	0.04	25.28	0.35	4.07	2.83
19	*Miconia albicans*	-1.77	0.05	-2.48	0.27	10.34	0.83	13.04	7.93
20	*Miconia ligustroides*	-2.03	0.04	-2.10	0.21	17.20	0.14	11.94	8.80
21	*Piptocarpha rotundifolia*	-1.40	0.06	-1.75	0.04	10.86	0.53	10.23	7.70
22	*Qualea dichotoma*	-2.36	0.00	-2.70	0.00	22.46	0.86	8.31	5.70
23	*Qualea grandiflora*	-1.91	0.01	-2.20	0.07	17.54	0.28	9.94	6.66
24	*Roupala sp.*	-2.46	0.01	-2.78	0.02	20.51	1.07	3.70	2.49
25	*Solanum lycocarpum*	-1.23	0.03	-1.98	0.30	14.40	0.28	12.64	7.21
26	*Styrax camporum*	-2.65	0.01	-2.90	0.00	29.47	0.50	5.68	4.23
27	*Stryphnodendron barbadetima*	-2.20	0.01	-2.55	0.04	25.68	0.94	15.46	11.37
28	*Stryphnodendron obovatum*	-1.99	0.00	-2.50	0.07	14.44	1.02	15.42	10.74
29	*Tibouchina stenocarpa*	-1.32	0.04	-1.69	0.01	9.38	0.59	10.05	7.12
30	*Tocoyena formosa*	-2.38	0.03	-2.80	0.07	20.83	0.44	11.21	8.40
	Mean value	-2.11	0.03	-2.50	0.07	19.66	0.54	10.27	7.23

No.	Species	Dry season πsat /MPa	Se / MPa	πtlp /Mpa	Se / MPa	ε /MPa	Se / MPa	Wsdlp %	Se %	Increment in dry season % πsat	πtlp	ε	Wsdtlp
1	*Anacardium nanum*	-1.87**	0.02	-2.50**	0.00	14.02	0.19	7.70**	0.11	-37.28	-72.41	9.81	133.69
2	*Anadenanthera falcata*	-2.52**	0.01	-2.90	0.07	31.12*	0.25	6.00	0.76	-12.20	-11.54	19.24	-40.61
3	*Annona coriacea*	-2.79*	0.04	-3.28**	0.09	24.80	0.64	6.70	1.25	-29.08	-39.36	4.59	-17.78
4	*Aspidosperma tomento-sun*	-2.55*	0.02	-3.00	0.00	16.24*	0.52	13.24	3.49	-6.49	-4.35	-22.48	12.54
5	*Bahuinia holophylla*	-2.12**	0.04	-3.00*	0.14	14.28**	0.11	8.32	0.02	-39.57	-51.90	77.73	-43.13
6	*Bowdichia virgilioides*	-2.57**	0.03	-3.00**	0.00	25.49**	0.04	9.08*	0.68	-22.97	-20.00	39.66	-48.07
7	*Campomanesia aro-matica*	-2.08**	0.01	-2.60	0.00	15.89**	0.49	7.08	1.20	10.02	3.70	-33.57	13.02
8	*Campomanesia sp.*	-2.14*	0.01	-2.60**	0.00	17.30**	0.14	7.77	0.09	18.67	13.33	-38.15	-22.49
9	*Caryocar brasiliense*	-2.07**	0.00	-2.70*	0.07	16.96*	0.10	13.33	2.14	-20.77	-22.73	49.57	-12.13
10	*Casearia sylvestris*	-2.75*	0.01	-3.18*	0.09	28.33	0.17	7.87	1.51	-11.99	-16.51	7.85	-15.69
11	*Connarus suberosus*	-2.28	0.00	-2.80	0.00	16.85	0.70	8.13	0.26	-1.27	-6.67	-6.41	-2.11
12	*Didymopanax vinosum*	-2.14	0.03	-2.90*	0.07	13.14	0.79	11.27	0.42	-9.63	-23.40	-11.93	-29.52
13	*Diospyros sp.*	-2.03*	0.01	-2.70	0.07	13.38	1.00	6.57*	0.04	3.56	-10.20	-8.64	-23.87
14	*Duguetia furfuracea*	-2.48**	0.03	-3.00*	0.00	17.02**	0.27	2.28*	0.02	14.48	9.77	-61.96	-29.13

Continued Table 1

No.	Species	Dry season								Increment in dry season %			
		πsat /MPa	*Se* / MPa	πtlp /Mpa	*Se* / MPa	ε /MPa	*Se* / MPa	*Wsdlp* %	*Se* %	πsat	πtlp	ε	*Wsdtlp*
15	*Erioteca gracilipes*	-2.08	0.04	-2.60	0.07	15.98	0.23	8.89	0.28	1.02	5.45	-9.85	-16.13
16	*Erythroxylon sp.*	-1.73**	0.03	-2.50*	0.00	7.42**	0.50	10.05	0.02	26.48	12.28	-66.18	-13.26
17	*Erythroxylon suberosum*	-3.04*	0.05	-3.50	0.00	33.74*	1.48	7.29	0.43	-43.40	-34.62	68.15	-41.30
18	*Memora axillaris*	-2.67	0.02	-3.25	0.00	17.69**	0.13	3.92	0.10	9.69	2.99	-30.01	-3.81
19	*Miconia albicans*	-2.37**	0.01	-3.00*	0.00	17.40*	0.43	7.92	0.25	-33.76	-21.21	68.23	-39.24
20	*Miconia ligustroides*	-2.07	0.05	-2.60	0.00	16.44	0.77	12.14	0.66	-1.90	-23.81	-4.43	1.68
21	*Piptocarpha rotundifolia*	-2.02*	0.02	-2.60*	0.07	13.04	0.59	8.50	0.73	-43.82	-48.57	20.12	-16.92
22	*Qualea dichotoma*	-2.26**	0.00	-2.90**	0.00	14.07**	0.03	7.36	0.07	4.62	-7.41	-37.37	-11.44
23	*Qualea grandiflora*	-2.10*	0.02	-2.50	0.07	16.25	0.39	4.29*	0.26	-9.69	-13.64	-7.35	-56.89
24	*Roupala sp.*	-2.54	0.07	-3.15	0.11	18.79	0.00	6.72*	0.47	-2.94	-13.51	-8.41	81.87
25	*Solanum lycocarpum*	-1.80*	0.10	-2.30	0.07	17.19	1.28	8.52	1.70	-46.53	-16.46	19.34	-32.61
26	*Styrax camporum*	-2.14**	0.02	-2.60**	0.00	15.95**	0.29	4.37	0.10	19.33	10.34	-45.88	-23.15
27	*Stryphnodendron barbadetima*	-2.81**	0.01	-3.15**	0.00	39.55**	0.75	5.61	0.35	-28.02	-23.53	54.01	-63.70
28	*Stryphnodendron obovatum*	-2.43*	0.06	-3.05*	0.00	20.29	0.93	14.11	1.15	-22.01	-22.00	40.55	-8.47
29	*Tibouchina stenocarpa*	-2.01**	0.05	-2.60**	0.00	15.25*	0.13	12.89	0.84	-52.07	-53.85	62.55	28.26
30	*Tocoyena formosa*	-1.96**	0.02	-2.60	0.00	13.72*	0.06	8.35	0.93	17.82	7.14	-34.12	-25.48
	Mean value	-2.28	0.03	-2.84	0.03	18.58	0.45	8.19	0.68	-7.99	-13.26	-5.45	-20.22

Notes: * -- significant difference comparing with the wet season($P< 0.05$), ** -- $P< 0.01$ after one way of ANOVA. πsat--osmotic potential at saturation, πtlp --osmotic potential at turgid loss point, ε--modulus of elasticity, *Wsdtlp* --The water saturation deficiency at turgid loss point of 30 woody, *Se*--standard error. The each parameter value of 30 species with the corresponding standard error (*Se*) was the mean value that obtained from measuring at least 3 times in wet or dry season and the increment (%) of each mean value in the dry season was compared with that in the wet season.

water relation is inverse.

On the other hand, the relation between the πsat and the ε in the wet and dry season is different. Responding to the water stress in the dry season, most species decrease their values of the πsat and increase the values of ε. Therefore, the figure and the equation parameters on the relation between the πsat and the ε have changed comparing with that of wet season (Fig. 1). However this regulation is not exactly followed by all species.

The strategy types for plants adjusting their water relation in Cerrado area

Plants adjusting their water relation to maintain their organs to be turgid is sophisticated because it is a kind of comprehensive responses to multiple stress in the field condition, which involve many mechanisms on morphology, physiology, phonology (Meinzer *et al* 1986). The πsat, the πtlp, ε and the *Wsdtlp* represent different aspects of water relation in balance mechanism. In the body of plant they should function integrally. In this sense, we consider classifying the water balance mechanisms of 30 species to be a few meaningful types according to all values of the πsat, the πtlp, the ε, the *Wsdtlp* and their changing tendency. In this way, general strategy for Cerrado species to balance water relation would be understood more objectively. We have used the Cluster Analysis method to build up the hierarchical tree of strategies of 30 species with the Euclidean Distance and the Complete Linkage. 30 species could be divided into 3 distinct types of the water balance mechanism when we used 30 as the linkage distance (Fig. 2).

The type 1 includes 18 species that consist of 60% of all species. When the linkage distance is 16, the group of these species has been joined together. Therefore, the characteristics of water balance parameters and their changing tendency are more uniform compared with other 2 types. These species have the highest mean value on the πsat, πtlp, being -1.93 MPa, -2.32 MPa respectively; the lowest mean value on ε, being 15.50 MPa; and the higher mean value on the *Wsdtlp*, being 11.05% in the wet season. When the dry season was coming, the value of πsat, πtlp of majority species went down enormously (15.38% and 21.10% on an average respectively). While the values of ε went up a little (7.131% on an average), the *Wsdtlp* also went down a little (3.42% on an average) to adapt the water stress (Table 2). This situation shows one principal strategy of this group species is to strengthen the ability to uptake water from habitant, stiffen their leaves and decrease the water content for maintaining their organs to be turgid.

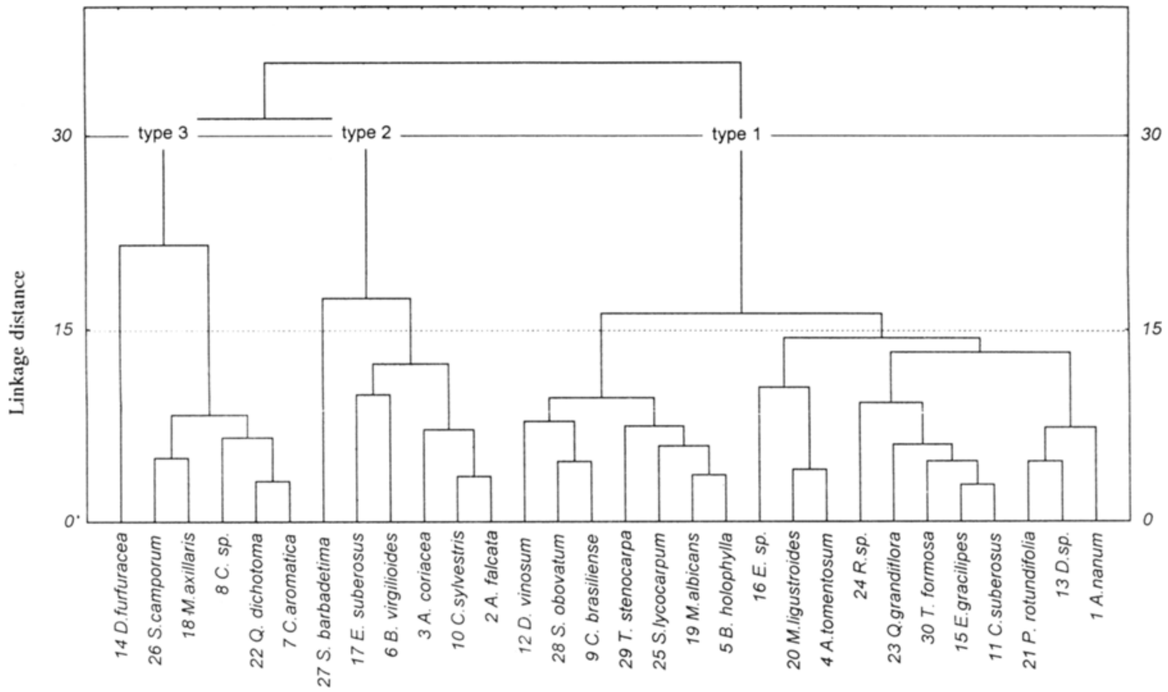

Fig. 2. The hierarchical tree diagram on water balance strategies for 30 species (number of each species is the same as that in Table1). The water balance parameters in wet and dry seasons have been subjected to Cluster Analysis (Tree Clustering) with Complete Linkage, and Euclidean Distance

The type 2 includes 6 species that consist of 20% of all species. When the linkage distance is 17.5, the group of these species has been merged together. Therefore, the characteristics of water relation parameters and their changing tendency are clearly unitary. These species have the lower mean values on the *πsat*, the *πtlp*, being -2.20 MPa, -2.55 MPa respectively, the higher mean value on *ε*, 23.08 MPa, and the highest mean value on the *Wsdtlp*, 12.06% in the wet season. When the dry season was coming, the values of *πsat*, *πtlp* of all species decreased (24.71% and 24.26% on an average respectively), while the values of the *ε* increase (34.57% on an average) and values of *Wsdtlp* decrease (37.85% on an average) to adapt the water stress (Table 2). The principal water balance strategy of this group of species is to strengthen enormously the ability to absorb water from soil, and stiffen greatly their leaves, decrease largely water content for maintaining their organs to be turgid in order to response the water stress in the dry season.

Table 2. The mean values of water balance parameters types of 30 Cerrado species in wet season and their increment in dry season

Types	No. Of species	Percentage %	*πsat* /MPa	Increment %	*πtlp* /MPa	Increment %	*ε* /MPa	Increment %	*Wsdtlp* %	Increment %
1	18	60	-1.93	-15.38	-2.32	-21.10	15.50	7.13	11.05	-3.42
2	6	20	-2.20	-24.71	-2.55	-24.26	23.08	34.57	12.06	-37.85
3	6	20	-2.64	13.15	-3.00	5.45	28.58	-40.78	6.26	-12.83

Notes: *πsat* --osmotic potential at saturation, *πtlp* -- osmotic potential at turgid loss point, *ε* -- modulus of elasticity, *Wsdtlp* -- the water saturation deficiency at the turgid loss point, Increment (%) -- their increment respectively in the dry season.

The type 3 also includes 6 species that consist of 20% of all species. Although this type of species has the longest linkage distance (20) to merged together, it also has clear unity on the water relation parame-

ters and their changing tendency. These species have the lowest mean values on the *πsat*, the *πtlp*, -2.64 Mpa, -3.00 MPa respectively, the highest mean values on the ε, 28.58 MPa, and the lowest mean value on the *Wsdtlp* 6.26% in the wet season. In the dry season, the values of *πsat* of all species and the values of the *πtlp* of 5 species increased 13.15% and 5.45% on an average respectively. While the values ε decreased 47.78% on an average and the *Wsdtlp* decreased 12.83% on an average to adapt the water stress (Table 2.). This group species themselves have lowest values on the *πsat*, *πtlp* in wet season, which means they have stronger ability to absorb water from soil. However, the organs of these species have weaker ability to store water because they have the highest values on the ε (Larcher 1995). Therefore, the principal strategy of this group of species is to strengthen the ability to store water in their organs, and correspondingly to weaken their ability to absorb water from soil, and decrease largely the water content in response to the water stress in dry season.

It is clear that the different types have the special mechanism to respond to the water stress. This situation shows the diversity on strategies of water balance in Cerrado.

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(**Responsible editor**: Zhu Hong)